Annealing Behavior of Dilute Cu Alloy Films

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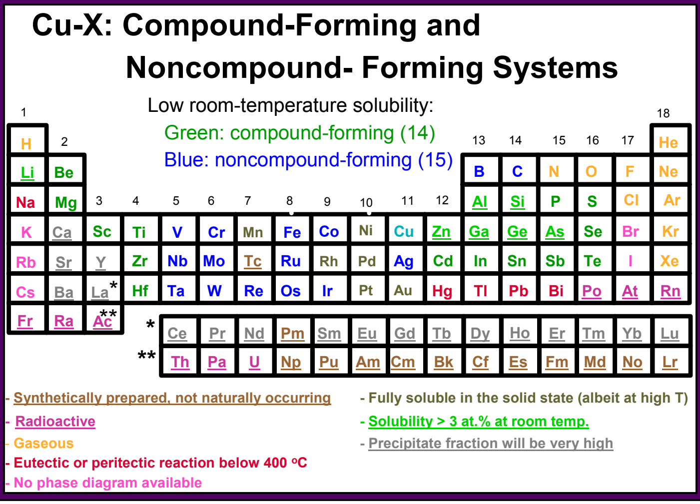
Motivation and Results

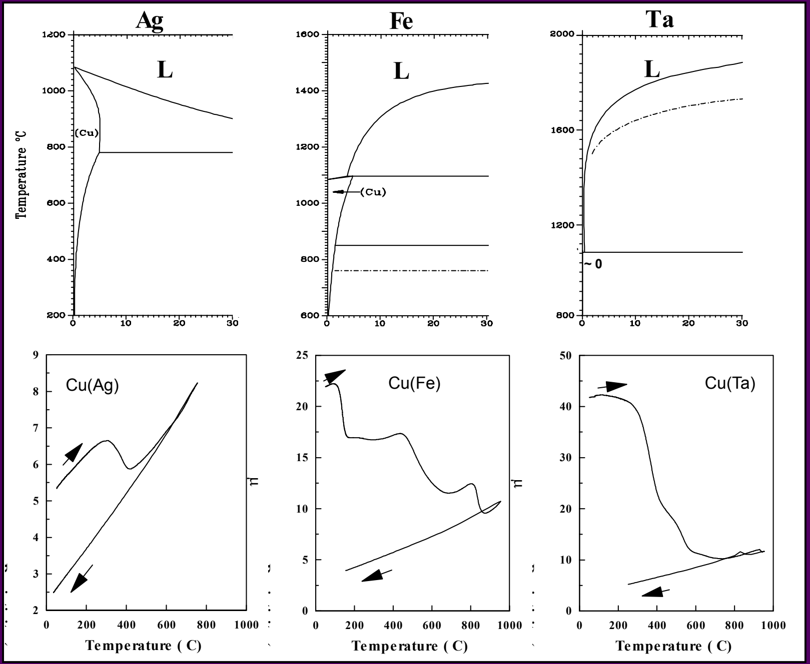
The need to reduce delays in integrated circuits and to enhance the electro-migration lifetime of interconnections prompted the replacement of Al(Cu) with Cu in the 1990's. However, as line widths decrease to 100 nm and below, the addition of alloying elements to tailor the grain size and texture, and thus the reliability and functionality, of Cu interconnections may become necessary.

Seven criteria have been developed to reduce the number of potential alloying elements for Cu from more than 100 to 34 (top figure).

Experimental investigations of resistivity, texture and grain structure of 17 alloy systems performed during the course of this research reduce the number of potential alloying elements to 32. W and Ir are found to be unsuitable on account of their unacceptably high post-annealing resistivities.

The resistivity-temperature behavior of the noncompound-forming alloy films is found to correlate with the form of the Cu-rich end of the binary phase diagram (bottom figure). Category I: Ag, Category II: Fe, Co, Ir, Category III: V, Nb, Ta, Cr, Mo, W, Re, Ru, Os, B, C.





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Broad Impact

• The experimental results serve as the scientific knowledge base for the potential selection of alloying elements for future interconnections in integrated circuits. The close interactions with industrial researchers increases the relevance of the work, without compromising its exploratory, fundamental nature.

• The students have been exposed to advanced characterization methods (*in situ* resistivity in combination with synchrotron X-ray diffraction) not available at CMU and have had the opportunity to work closely with industrial researchers.

• The *in situ* resistivity and synchrotron XRD experiments on Cu alloy films were performed at the IBM T. J. Watson Research Labs and/or at the IBM X20C beamline at the National Synchrotron Light Source (NSLS) at the Brookhaven National Laboratory (BNL). The TEM and texture studies were carried out at CMU.

Example Publications (25 total)

K. Barmak, A. Gungor, C. Cabral, Jr., and J. M. E. Harper, “Annealing behavior of Cu and dilute Cu-alloy thin films: Precipitation, grain growth and resistivity”, *J. Appl. Phys.* **94**, 1605-1616 (2003).

A Gungor, K. Barmak, A. D. Rollett, C. Cabral, Jr., and J. M. E. Harper, “Texture and resistivity of dilute binary Cu(Al), Cu(In), Cu(Ti), Cu(Nb), Cu(Ir) and Cu(W) alloy thin films”, *J. Vac. Sci. Technol. B* **20**, 2314-2319 (2002).

Education

Five graduate students and several IBM researchers (Cabral, Harper, Lavoie, Rodbell) were involved in this work. Three students graduated at the doctoral level.

• Graduate student Gene Lucadamo is a post-doctoral researcher at Sandia Laboratories, Livermore. Graduate student Scott Tong is a post-doctoral researcher at the University of Wisconsin. Graduate student Ali Gungor has returned to Turkey and is a faculty member.